Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	**)**	
	)	
Establishment of an Interference Temperature	**)**	
Metric to Quantify and Manage Interference	**)**	ET Docket No. 03-237
and to Expand Available Unlicensed	**)**	
Operation in Certain Fixed, Mobile and	**)**	
Satellite Frequency Bands	**)**	

<u>REPLY COMMENTS OF SHARED SPECTRUM COMPANY</u>

William J. Byrnes

7921 Old Falls Road
McLean, VA 22102-2414
703-821-3242

Mark A. McHenry
Alexe E. Leu
8133 Leesburg Pike, Suite 220
Vienna, VA 22182
703-761-2818 x 103

April 5, 2004

TABLE OF CONTENTS

SUMMARY

Dynamic sharing of spectrum is best achieved by hole filling rather than by underlay. Dynamic sharing can provide a system that will evolve over time to take into account changing regulatory requirements, experience in operation, and shifts in the degree of usage among primary users in each band. This will obviate the need in the future simply to kick out older less efficient users of spectrum to make room for newer more attractive and efficient users. Initially, cognitive radios should be operated on a centrally controlled system basis.

There is need now for the adoption of the concept of controlling interference by interference temperature limits as a general metric, with an initial level to be set in the future at 3 dB below the typical noise figure (NF) of the affected transceiver the band. Claims that CDMA systems would be drastically curtailed are completely inaccurate, and are dependent, among other mistakes, on the misuse of the Shannon limit concept and a failure to take into account other characteristics of the technology.

Substantial public benefits, both in the short run and in the long run, from introduction of dynamic sharing technology, including, among others users, of public service communications. The Commission should emphatically reject attempts to monopolize the large amount of spectrum made available through dynamic sharing by large incumbents arguing that they should be given exclusive control over the spectrum and competitors should be barred on an _a priori_ basis.

Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	**)**
	)
Establishment of an Interference Temperature	**)**
Metric to Quantify and Manage Interference	**)** ET Docket No. 03-237
and to Expand Available Unlicensed	**)**
Operation in Certain Fixed, Mobile and	**)**
Satellite Frequency Bands	**)**

<u>REPLY COMMENTS OF SHARED SPECTRUM COMPANY</u>

<u>Hole Filling, Rather than Underlay, is the Likely Paradigm for Future Sharing</u>

One possible source of confusion is the assumption by a number of commenting parties that what is being addressed are merely "underlay" systems that operate indiscriminately without regard to the primary users in each band. Shared Spectrum believes that the far more effective technology and future paradigm will consist of systems that find and use "holes," both spatial and temporal, for their transmissions. Shared Spectrum is developing such a system. The Shared Spectrum system identifies fallow spectrum on a dynamic basis and uses it if it meets an appropriate selection algorithm.

Figure 1 Cognitive Radios will act as a spectrum gap filler between Affected Users.

A major component of the sharing algorithm is the Interference Temperature limit, which establishes the spatial and frequency separation between the Cognitive Radio signals and the Affected Transceiver. The power level received by the Affected Receiver from the Cognitive Radios needs to be below the Interference Temperature limit. An interference temperature limit needs to be set and selection limited to potential holes that fall within that limit. In its Comments in this proceeding, Shared Spectrum has suggested as an initial interference temperature limit 3 dB below the typical noise figure (NF) of the Affected Transceiver in a band.

Shared Spectrum Offers a Flexible System Which Can Develop Over Time

Holes that are large and durable obviously preferred to holes that are small and evanescent. That proposition can be reflected in a well designed algorithm, and the algorithm can be adjusted over time to reflect increasing degrees of confidence in operational experience and increasing congestion progressively limiting frequency selection opportunities.

Because the system uses software defined radio, its parameters can be readily adapted to experience, the Commission's evolving requirements, and shifting market demand.   The system can be developed in an evolutionary way in response to market demands and without the discombobulations created when the Commission is forced to take the drastic step of moving out users of older technologies to make room for newer ones.   To provide an additional degree of security regarding interference concerns, Shared Spectrum suggests that initially smart radios be operated on a licensed system basis with central control over the software in each transceiver so that the software can be adjusted instantly to respond to any harmful interference that may be experienced or any direction by the Commission. After experience has demonstrated to all that the

technology can be operated with complete confidence, then individual transceivers
should be permitted to operate on an unlicensed basis.

The Need is for Conceptual Adoption of a General Metric

The Inquiry part of this proceeding basically addresses the conceptual adoption
of a general metric. When that conceptual metric has been chosen, the next step will be
the quantification of specific limits for each band. Some bands are obviously more
suited for early implementation of dynamic sharing than others. Much of what has been
said in initial comments relates to the question of quantification of limits in particular
bands and the suitability of particular bands. While these questions are important ones,
they do not need to be settled immediately. The more immediate task is the
establishment of a conceptual structure with which such other questions can be
addressed in detail.

The Claim that CDMA Services Would Be Specially Impacted is Spurious

A number of parties (including Verizon Wireless, QUALCOMM, V-Comm)
advance the argument that even a small increase in noise temperature would drastically
curtail the coverage of the CDMA network. The use by these parties of the formula for
the Shannon capacity limit was inappropriately applied, a number of major factors
mitigating any such effect were simply ignored, and their resulting conclusion are
unsupported. Their conclusion is completely wrong. Actually CDMA is at most only
slightly affected by the interference temperature. As discussed in detail in Appendix A
hereto, interference temperature does not produce significant harm.

Dynamic Sharing Will Bring Substantial Public Benefits

Moreover, the introduction of the new sharing technology would generate substantial, broad-based economic benefits for the nation both in the long and short-term. Short-term benefits would arise from: (1) the specific benefits that would flow to the public safety entities (and those they serve) whose operations would be made more efficient by use of the technology (2) the efficiencies that it would bring to a wide variety of radio system applications throughout the economy. When each new service in turn must run the gauntlet of a separate regulatory process, the resulting risks and the delays strongly dampen the innovative impetus. Shared Spectrum is developing a technology that permits expansion along several trajectories depending on acceptance in market factors. Below we explain each of these points.

One relatively short-term beneficial output of the technology would be a specific system providing communications infrastructure for public safety agencies at major incidents such as terrorist attack, large forest fires or major airplane crashes. The system would provide public safety agencies the ability to use commercial off-the-shelf hardware and software, such as personal computers and PDAs, to support high-speed (50 Mbps), high-capacity (multiple simultaneous paths), relatively long range (10s of kilometers), interoperable data communications. Operating infrastructure could be established within hours at large incidents. Similar infrastructure could be established in urban areas to support ongoing communications needs as well as to provide support during such incidents.

The growth of the Internet and the widespread use of wireless LANs, most notably WiFi (IEEE 802.11), has resulted in today's environment in which most portable computers come with software support for wireless media, TCP/IP, and client software

for email, conferencing, and web access.[1] The proposed system would allow a public safety agency to install a PC Card device into a personal computer and establish communications with the infrastructure using the preexisting software in the personal computer. Unlike the case of commercial 802.11 wireless LANs, which are restricted by FCC-imposed power limits to short range operations—typically less than 100 meters, the proposed system would have a range of many kilometers. Similarly, the system could support multiple connections at the same time. The familiar 802.11b wireless LAN technology supports only three simultaneous transmissions in the same area—setting a limit on the total capacity at any hotspot.

Public safety agencies have begun to use wireless LAN technology in several modes including for routine local networking in offices, for communications to mobile units needing data capabilities, and for use at incidents Use of a wireless LAN at an incident poses several problems that are not encountered in routine use:

- infrastructure may be lacking,

- infrastructure coverage may be inadequate, and

- radio spectrum may not be available.

Wireless LANs require access points (APs) with radio connections on one side and backhaul connections to the wider Internet on the other. Conventional APs are installed where the need for communications is foreseen in advance and have limited range. Conventional APs share the radio spectrum with other unlicensed communications devices, such as cordless telephones and radio amateurs, and with non-communications devices such as microwave ovens. Thus, it is likely that many incidents will occur in areas lacking preexisting access point coverage. Conventional wireless LANs at incidents may have to share radio spectrum with wireless LANs in

---

[1] All major personal computer operating systems, MS Windows, Apple OS-X, and Linux support both 802.11 PCC ard interfaces and TCP/IP connectivity over 802.11 devices.

nearby offices or used by others, such as news media or bystanders, located at or near the incident scene.

The project will develop infrastructure that remedies these shortcomings. The system infrastructure would:

- be able to operate on spectrum not shared with other wireless LAN users,

- provide coverage of 10 to 20 km from a single access point,

- be deployable on short notice, and

- provide incident management tools such as web servers, email connectivity, chat tools, and shared databases.

Paired with the infrastructure would be matching mobile radio units with PC Card, USB, or Ethernet interfaces that could be installed in or connected to portable computers and similar user devices. Client software would also be made available that would permit access to applications for those devices lacking the necessary software.

The basic mode of operation would be for a unit arriving at the incident to obtain a PC Card from the incident commander, plug that PC Card into a computer, and establish connectivity. The unit would then have reliable Internet connectivity back to the unit's own home base and to the wider Internet. The unit would also have access to the communication tools, such as web servers and data bases, collocated with the base station. These tools would provide the incident commander with an efficient and reliable mechanism for communication with units and unit commanders from various jurisdictions.

Large incidents occur regularly. For example, the California Department of Forests and Fires (CDF) reports that it was involved with the suppression of 93 fires

covering more that 300 acres during the year 2002.[2] The CDF maintains 11 mobile

kitchens each capable of serving 2,000 people per day.

Interoperability poses a consistent problem in public safety communications. The

public safety interoperability problem has been recognized for decades but the problem

persists because of multiple technical, economic, and social constraints. The proposed

system would provide a valuable interoperability asset, one capable of supporting units

from many jurisdictions, without requiring advance investment or training by those

jurisdictions.

Quantifying the benefits from improved communications at major incidents poses

difficulties—there is no simple mapping from communication improvements to public

safety system performance to property and lives saved. However, we can estimate

rough bounds. FEMA reports that direct property loss in the United States due to fires

was $10.3 billion in 2002. In addition, 3,380 civilian deaths were caused by fire. There

are about 300,000 full-time professional firefighters.[3] Major incidents comprise only a

small fraction of fires and a larger proportion of the costs of fires. A 1% decrease in

direct costs of fires would generate annual benefits of $100 million per year. Discounting

an annual flow of such benefits to the present at 2% yields a net present value of

benefits of $5 billion.[4]

More fundamentally, the technology will provide an important new tool in

managing the radio spectrum resource, i.e. the range of usable radio frequencies and

the permission to operate transmitters on those frequencies. The radio spectrum is

---

[2] http://www.fire.ca.gov/FireEmergencyResponse/HistoricalStatistics/HistoricalStatistics.asp.

[3] Fire Data Web page at http://www.usfa.fema.gov/inside-usfa/nfdc/nfdc-data11.shtm.

[4] A 2% interest rate may seem low to one familiar with typical high-tech venture funding. However, we believe it to be the appropriate rate for such social benefits. See The Rate of Discount for Evaluating Public projects, by R. F. Mikesell, AEI, 1977.

often regarded as a flow resource divided by elements of time, space, and frequency.[5]

Originally, the radio spectrum was divided among alternative users by means of administrative tools that were based on static information such as written databases. Such tools reflected the information technology available at the time they were developed. They also reflect tradeoffs between administrative cost, system reliability, and system quality and political choices regarding the amount of radio spectrum that should be made available to various services such as broadcasting, cellular, public safety. As with many information systems, the radio spectrum management system has substantial inertia and still depends on mechanisms that were forged in a pre-computer world. Radio technology underlies key portions of the economy including broadcasting, satellite and cable TV, mobile communications, emergency communications, and air traffic control. Spectrum is to communications as petroleum is to transportation—a key input. It is not unreasonable to conclude that use of the radio spectrum contributes directly to about 5% of the GDP and even more indirectly. Given that the annual GDP is $11 trillion, this amounts to annual value added of $550 billion.

The project will deliver a new capability— a system able to manage the use of spectrum on a non-interference basis dynamically, matching spectrum demand to spectrum availability on a time scale of minutes rather than the decades of the traditional system, over a wide swath of spectrum and geography. Such capabilities can be used by the Commission to permit opportunistic but non-interfering spectrum use to authorize dynamically subscriber operation by service providers to manage the subleasing of their radio spectrum. Even a slight increase in the efficiency of the use of the radio spectrum would generate annual benefits of billions of dollars per year. The system will facilitate

---

[5] See http://www.itu.int/ITU-R/ and FCC Radio Spectrum Home Page, http://www.fcc.gov/oet/spectrum/.

access to and use of spectrum by a variety of users. In economists' jargon, it increases

the supply of spectrum.

Adoption of the framework proposed here will permit increase in spectrum use to

develop in a market-driven evolutionary way. There will be no need for the Commission

to undertake the increasingly painful process of kicking out older and less efficient

services band by band in order to make spectrum available for new technology that

better serves current needs. Dynamic sharing will permit the introduction of substantial

additional communications capacity as the market demands it without the need to order

existing users to cease and desist their operations.

Spectrum Sharing Facilitates Healthy Competition

The comments of some parties focus on special situations. One such special

condition exists with respect to the case where a significant frequency band is currently

licensed over a significant area to a single licensee. Some such licensees who currently

don't engage in sharing of any kind are not satisfied with assurance that their existing

operations will be afforded ample assurance that interference will be avoided. They

want unlimited ability to increase their usage in a variety of ways in the future without

being at all inhibited by other spectrum users.

Illustrative of this special case is Verizon Wireless, which devotes the entire

Section II of its Comments to an alleged incompatibility of interference temperature with

what it calls "proper economic analysis." Its notion of "proper economic analysis" turns

out, on closer inspection, to be nothing more than a return to the now discredited

economic analysis that was used for many years to justify the Bell System monopoly.. It

justifies its refusal to tolerate any other use within what it considers its bands no matter

how innocuous on the basis that it and it alone will achieve greater efficiencies of band

usage in the future. It argues that nothing must be allowed to compete with its potential

future improvements. This is essentially the position taken by the Bell System when it opposed the introduction into its monopoly wireline telephone network of specialized common carriers[6] and customer-provided equipment[7] (which it referred to as "foreign attachments.") Now and then a dominant carrier proclaims fear of allegedly enormous damage to its operations by even the most modest introduction of use by parties not under its direct control. The allegations here of enormous potential harm turn out to be based on worst case assumptions, incorrect use of the Shannon limit and disregard of factors characteristic of its own service. It is shown to be fundamentally flawed in the Appendix to these Reply Comments.

Verizon seeks to rule out at the outset a new type of service and not permit it to be tested in the marketplace with vague assertions that if the Commission gives it complete control over everything taking place in the bands in question it's unitary control will be more productive than would be the opening of the bands to a degree of competition with new services.   The instinct of firms with established market power is to suppress technological innovation and that is what Verizon seeks to do here. Verizon is certainly not precluded from developing its own smart radio services, but it prefers instead to try to suppress new technology and deprive others of the incentive to pursue it.

Verizon is, in effect, asking for monopoly control over the bands it is using by regulatory exclusion of new technology. Its position is essentially a reiteration of the old

---

[6] For example, the President of AT&T Long Lines testified in court that interconnection with new carriers would seriously damage the integrity of the nation's telephone network. MCI Communications Corporation v. ATT, U.S.D.C. E.D. Pa. Civil Action No. 73-2499 at 328-341. (See The Communications Act: A Legislative History of Major Amendments, 1934-1996, Paglin ed. 1999.) The Commission's disposition of these spurious claims is found at Bell System Tariff Offerings, 46 FCC2d 413 (1974), aff'd sub nom. Bell Telephone Co. of Pennsylvania v. FCC, 503 F.2d 1250 (3d Cir. 1974), cert. denied, 422 U.S. 1026 (1975).

[7] Carterfone Device in Message Toll Telephone Service, 13 FCC2d 420, aff'd 14 FCC2d 571 (1968).

Bell monopoly theory (once described by the slogan "The System is the Solution" and sometimes identified with the "Vail Paradigm)" that the Commission and history have squarely rejected.   It is well established, however, that competition is the most effective agent for development and implementation of new technology.   The Commission has recognized over the last generation that competition is the key to development of the most efficient services and that is the presumption that should be applied here.

Verizon points out the distinctive feature of cellular or PCS service of moving toward lower power operation to enlarge capacity. It cites the V-COMM measurements of particularly low operating noise figures that are said to be only slightly above the thermal noise floor. But Shared Spectrum's system is adjusted to reflect the primary receiver noise levels for primary users in each band and Shared Spectrum has proposed use of the figure of 3 dB below the typical noise figure as the appropriate initial limit for secondary smart radio operation. Thus, while the point made by Verizon is certainly relevant to what the interference temperature limits should be in the bands it uses, it is not really relevant to the question of the appropriate conceptual framework that is being addressed here. The low power of the primary users of the bands is a significant factor in making a market-based technical judgment that they may not be attractive candidates for early implementation of shared use. It is hard to escape the impression, however, that Verizon is attempting to bootstrap a technical point that is already covered by plans for the new technology into a device for convincing the Commission to make some sort of unnecessary ruling conferring monopoly privileges on it that will entail a priori exclusion of any future spectrum sharing beyond its complete control.

The economic theory propounded here by Verizon would, if adopted, set back the Commission's economic policy a generation. The Commission has consistently found in favor of competition in every area it regulates. Verizon's theory is that the dominant firm should have complete unitary control over necessary resources in order to

11

achieve economic efficiency.   This is Verizon's reincarnation of the Vail Paradigm in the garb of a discussion of engineering principles. While it occasionally refers to its theory as a matter of established Commission "spectrum policy," it was only the apparent absence of any sharing alternative, that left it in sole control over a portion of the spectrum and not an economic policy in favor of Commission-conferred market control. [8]

This theory has also been rejected by other agencies in addition to the FCC. For example, United Airlines, if it had the audacity of Verizon, could argue that it should have complete control over the use of the skies for air transport since it could then efficiently distribute the air traffic without the need to coordinate with other parties. The Government, however, has pursued, instead, a policy of airline competition with only the minimally necessary technical rules to avoid interference with one another's operations, such as the maintenance of minimum separations between aircraft. (And just as aircraft seldom come close to the minimum separation requirements, Shared Spectrum's hole-finding technology would seldom even come close to an interference temperature limit.) Competition has borne fruit for the public. The most successful airline operation is currently Jet Blue, a smaller newcomer, which pursues a different service concept than had been pursued by the much larger and more established airlines.   If the economic theory propounded here by Verizon had been employed in air transportation, however, the entry by Jet Blue would have been precluded at the outset and the public would have been ill-served. Such regulatory preclusion of entry should not be allowed to thwart vital new services such as that made possible by Shared Spectrum.

---

[8] The current Verizon argument bears a significant resemblance to the Bell System argument that it had been given a Commission-sanctioned monopoly over interstate telephone service that was rejected by the courts in the "Execunet case," MCI Telecommunications Corporation v. FCC, 561 F.2d 365 (D.C. Cir.), cert denied, 434 U.S. 1040 (1978), mandate enforced, 580 F.2d 590 (D.C. Cir 1978), cert. denied, 439 U.S. 980 (1978).

CONCLUSION

The Commission should adopt as a general policy the principle that cognitive radios should be regulated in terms of an interference temperature limit to be adopted with respect to each band initially at a level 3 dB below the typical noise figure (NF) of the affected transceiver the band.

Respectfully submitted,

Shared Spectrum Company

William J. Byrnes

7921 Old Falls Road
McLean, VA 22102-2414
703-821-3242

Mark A. McHenry
Alexe E. Leu
8133 Leesburg Pike, Suite 220
Vienna, VA 22182
703-761-2818 x 103

April 5, 2004

In the Matter of	**)**	
	)	
Establishment of an Interference	**)**	
Temperature Metric to Quantify and Manage	**)**	ET Docket No. 03-237
	)	
Interference and to Expand Available	**)**	
Unlicensed Operation in Certain Fixed,	**)**	
Mobile and Satellite Frequency Bands		

APPENDIX A TO REPLY COMMENTS OF SHARED SPECTRUM COMPANY

**THE EFFECT OF INTERFERENCE-TEMPERATURE-BASED SHARING
ON CDMA SYSTEM CAPACITY**

The analysis of the effect of using the interference-temperature metric to govern spectrum sharing by QUALCOMM, Verizon Wireless and allied parties in this proceeding is fundamentally faulty and premised on inappropriate application of a theoretical model. In the following five sections we provide an accurate analysis of what is actually involved.

In Section 1, we introduce the log-distance path loss model with shadowing. Because of the random nature in the path loss due to the factors such as shadowing, the cell coverage is not uniquely determined but must instead be specified on the basis of outage system probability as described in Section 2.

Section 3 contains the proof that the mathematical expression used by QUALCOMM for the cell radius reduction is generally valid for <u>any</u> wireless cellular

system based on any kind of the radio access technology, including FDMA, TDMA, CDMA, etc. The question presented here, however, is the specific impact of the interference temperature on the performance of CDMA systems. QUALCOMM failed to specify the outage probability for which it has claimed that the cell radius is reduced by about 20%. Its analysis is faulty.

In Section 4, we show that QUALCOMM should clearly state the sizes of its cell coverage areas for urban, suburban, rural, indoor, etc, along with the outage probabilities as accurately as possible in light of the details for CDMA technologies. Our analysis reveals only upper bounds of system outage probabilities for any mobile technology in order to illustrate the fundamental mistake in QUALCOMM analysis. It is clear that any detailed analysis of the particular wireless access system would imply much less impact on the system than our very conservative and overestimated performance losses due to interference temperature requirement. Therefore, there is no need to increase the number of the cell sites due to the interference temperature. Also, the mobile users can still operate at the same transmit power parameters without perceiving any significant decrease in terms of quality of service rather than 0.2% increase in outage probability. We note that there will not be any shortage in the battery life.

In Section 5, the impact of the interference temperature on the system capacity is accurately evaluated. It is important to note that for the case of the wireless cellular systems, the capacity evaluation should be based on adequate expression for CDMA multi-cell capacity[9,10] and not based on the formula for Shannon capacity limit as Verizon

---

[9] A. M. Viterbi and A. J. Viterbi, "Erlang Capacity of a Power Controlled CDMA System," IEEE JSAC, vol. 11, No. 6, Aug. 1993.

[10] K. S. Gilhousen, et. al. "On the Capacity of a Cellular CDMA System," IEEE Trans. On Vehicular Technology, Vol. 40, No.2, May 1991.

Wireless has indicated. It does not make sense to show the calculations for the impact of the interference temperature on the Shannon capacity considering the bandwidth of 30 MHz. We provide a rigorous analysis of CDMA system capacity versus interference temperature.

In our original comments on this proceeding, we proposed an Interference Temperature level that is 3 dB <u>below</u> the pre-amplifier thermal noise level. We will show below that increasing the noise by 15 dB <u>above</u> the noise level, the CDMA capacity is unchanged. The unmistakable conclusion is that a small increase in Interference Temperature does not significantly affect the CDMA system capacity.

1. **Log-Distance Path Loss with Shadowing**

As a mobile user moves away from its base station, the received signal becomes weaker because of the growing propagation attenuation with the distance. Let $\overline{L}_p(d)$ denote the log-distance path loss[11], which is a function of the distance d separating the transmitter and the receiver. Then

$$\overline{L}_p(d) = \overline{L}_p(d_0) + 10\gamma \log\left(\frac{d}{d_0}\right) dB, d \geq d_0$$

---

[11] J.W. Mark and Weihua Zhuang "Wireless Communications and Networking," Prentice Hall,2003.

where γ is the path loss exponent and d_0 is the close-in reference distance.

The following table gives the typical values of the path loss exponent in different propagation environments.

Environment	Path Loss Exponent, γ
free space	2
urban cellular radio	2.7 to 3.5
shadowed urban cellular radio	3 to 5
in building with line of sight	1.6 to 1.8
obstructed in building	4 to 6

Furthermore, as the mobile moves in uneven terrain, it often travels into a propagation shadow behind a building or a hill or other obstacle much longer than the wavelength of the transmitted signal, and the associated received signal is attenuated significantly. This phenomenon is called "shadowing." A log-normal distribution is the model normally used for characterizing the shadowing process. Long-term fading is a combination of log-distance path loss and log-normal shadowing. Let $\varepsilon(\mathrm{dB})$ be a zero-mean Gaussian distributed random variable (in dB) with standard deviation σ_ε (in dB). The pdf of $\varepsilon(\mathrm{dB})$ is given by

$$f_{\varepsilon(\mathrm{dB})}(x) = \frac{1}{\sigma_\varepsilon \sqrt{2\pi}} \exp\left(-\frac{x^2}{2\sigma_\varepsilon^2}\right).$$

Let $L_p(d)$ denote the overall path loss with shadowing (long-term fading) in dB. Then,

$$L_p(d) = \overline{L}_p(d_0) + \varepsilon_{dB}$$
$$= \overline{L}_p(d_0) + 10\gamma \log\left(\frac{d}{d_0}\right) + \varepsilon_{dB}, d \geq d_0$$

The first-order statistics of log-normal shadowing are characterized be the standard deviation σ_ε (in dB), which can be derived from measurements. For example, 8 dB is a typical value for σ_ε (in dB) in an outdoor cellular system and 5 dB is a value for an indoor environment.

2. Radio Cell Coverage

Radio cell coverage is the service area supported by each base station. The coverage depends on service quality requirements, such as the required ratio of the signal power to interference-plus the noise power, or the required minimum received signal power level given the transmitted signal power, and (b) the propagation environment. <u>Because of the random nature in the path loss due to factors such as shadowing, the cell coverage is not uniquely determined but must instead be specified on the basis of statistical parameters.</u> Further, we illustrate how to determine the cell coverage for a given propagation model, where the service quality criterion is specified in terms of the propagation loss.

With shadowing, the relative path loss in dB at a distance $d (> d_0)$ with respect to the loss at d_0 is given by

$$\Delta \overline{L}_p (d) = 10 \gamma \log \left(\frac{d}{d_0} \right) + \varepsilon_{dB}, d \ge d_0$$

At the distance $d = r(> d_0)$, the probability P_{out} that the received signal strength at location $d = r(> d_0)$ is below the threshold P_n is given by Equation 1:

$$P_{out} = \Pr\left(-10 \gamma \log r + \zeta < P_n \right) = 1 - Q\left(\frac{P_n + 10 \gamma \log r}{\sigma} \right)$$

where:

$$Q(y) = \frac{1}{\sqrt{2\pi}} \int_y^\infty e^{-x^2/2}.$$

3. Coverage Reduction Versus Interference Temperature

Below, we show how the expression used by QUALCOMM to asses the reduction of the cell radius, can be obtained using a general expression for outage probability given in

Equation 1. Let the interference temperature be I_T and the parameter Δ such that $I_T = P_n \Delta$. In decibels' scale the expression of interference temperature becomes $I_T(dB) = P_n(dB) + \Delta(dB)$.

From Equation 1 we can determine the radius r of the cell given the outage probability P_{out} using the following formula:

$$r = 10^{-\frac{P_n(dB) - Q^{-1}(1 - P_{out})\sigma}{10\gamma}}$$

Now, the radius of the cell coverage imposing the interference temperature is given as below:

$$r^* = 10^{-\frac{P_n(dB) + \Delta(dB) - Q^{-1}(1 - P_{out})\sigma}{10\gamma}}$$

The cell radius reduction factor c_r is given by the following expression

$$c_r = \frac{\Delta r}{r} = \frac{r - r^*}{r} = \frac{10^{-\frac{P_n(dB) - Q^{-1}(1 - P_{out})\sigma}{10\gamma}} - 10^{-\frac{P_n(dB) + \Delta(dB) - Q^{-1}(1 - P_{out})\sigma}{10\gamma}}}{10^{-\frac{P_n(dB) - Q^{-1}(P_{out})\sigma}{10\gamma}}} = 1 - 10^{-\frac{\Delta(dB)}{10\gamma}} = 1 - \Delta^{-\frac{1}{\gamma}} ,$$

which is the expression used by QUALCOMM to justify the coverage reduction in CDMA system. Thus, we have shown how the expression used by QUALCOMM can be obtained without making use of any particular assumption with respect to CDMA technology. This expression is generally valid for any wireless cellular system based on any kind of the radio access technology, including FDMA, TDMA, CDMA, etc. The question presented here, however, is the specific impact of the interference temperature on the performance of CDMA systems. QUALCOMM failed to specify the outage probability for which it has claimed that the cell radius is reduced by about 20%. Its analysis is faulty.

We now evaluate the outage probability increase due to the introduction of the interference temperature metric and the putative decrease in the CDMA system capacity. The expression of the outage probability above is the simplest metric for a

6

rough estimate of the radio coverage for any multiple access technology and it is not specific to CDMA cellular systems. An accurate quantification of the impact of the interference temperature metric on CDMA cellular systems might be revealed by application of a suitable model for CDMA cell coverage that considers the soft handoff[12]. Using such a model, the interference temperature can be traded off with the radius reduction and outage probabilities.

4. Outage Probability Versus Interference Temperature

The increase in the number of cell sites due to the introduction of the interference temperature can be determined only based on the tradeoff among outage probability increase factor, radius reduction factor and system capacity. In this section, we analyze the increase factor of the outage probabilities given the interference temperature level. Let the increase factor of the outage probability be as follows:

$$c_{out}(r,\Delta) = P_{out}(r,P_n\Delta) - P_{out}(r,P_n)$$
$$= Q\left(\frac{P_n(dB) + \Delta(dB) + 10\gamma \log r}{\sigma}\right) - Q\left(\frac{P_n(dB) + 10\gamma \log r}{\sigma}\right).$$

Below, we illustrate the outage probabilities versus distance and outage probability increase versus interference temperature considering the decay parameter $\gamma \in \{3.0, 3.3, 3.8, 4.0\}$ according to QUALCOMM's comments. "The background noise, P_n, establishes the required received power signal at the cell site, which in turn fixes the cell radius for a given maximum transmitter power."[13]

---

[12] A. J. Viterbi, et. al. "Soft Handoff Extends CDMA Cell Coverage and Increases Reverse Link Capacity," IEEE JSAC, Vol. 12, No. 8, Oct. 1994.

[13] K. S. Gilhousen, et. al. "On the Capacity of a Cellular CDMA System," IEEE Trans. On Vehicular Technology, Vol. 40, No.2, May 1991.
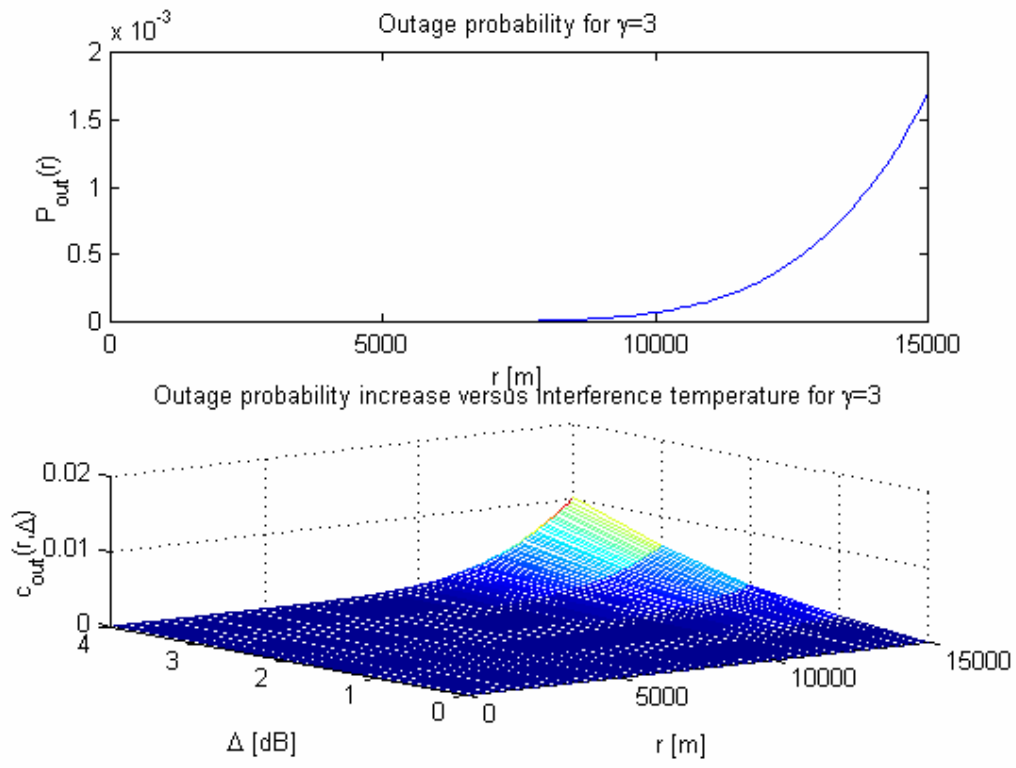
Figure 2: Outage vs. interference temperature for $\gamma = 3\,\mathrm{dB}$.

In Figure 2 we observe that for $\gamma = 3\,\text{dB}$ the outage probability is less than 0.002 within a distance of 15 Km. The increase in the outage probability due to 4 dB of interference temperature is less than 1%, which indicates that the impact on the system performance is negligible.
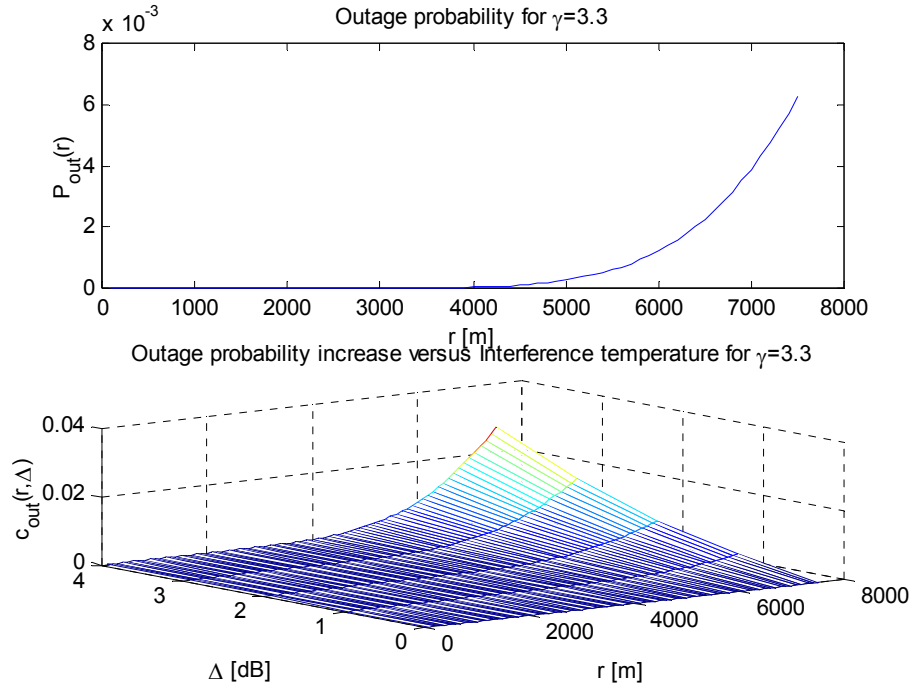

Figure 3: Outage vs. interference temperature for $\gamma = 3.3\,\text{dB}$.

In Figure 3, we observe that for $\gamma = 3.3\,\text{dB}$ the outage probability is less than 0.002 within a distance of 7.8 Km. The increase in the outage probability due to 4 dB of interference temperature is less than 1%, which indicates that the impact on the system performance is completely negligible.
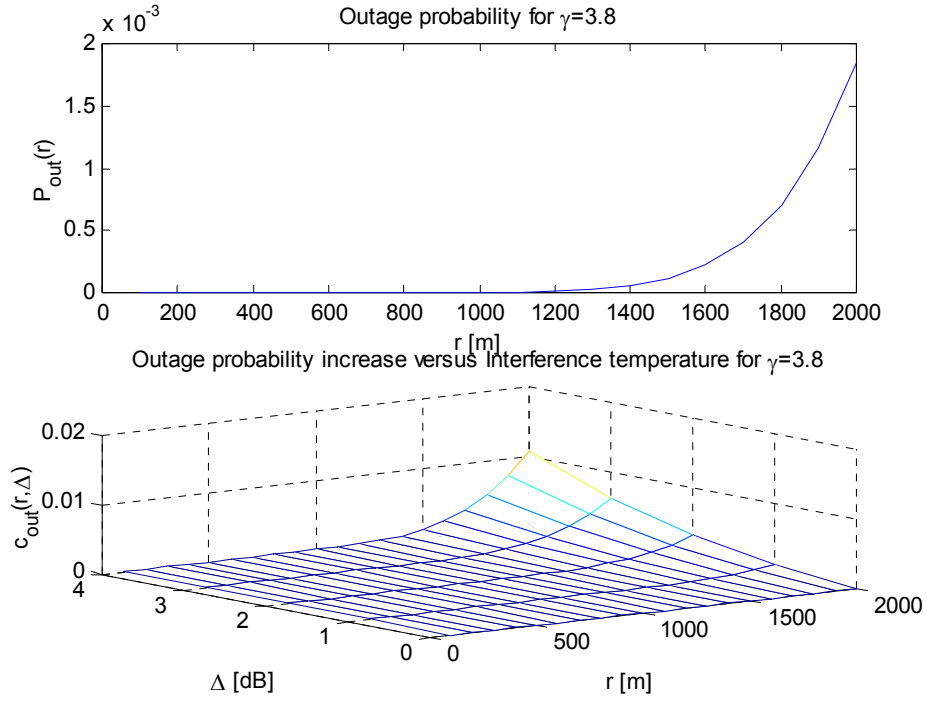
Figure 4: Outage vs. interference temperature for $\gamma = 3.8\,\text{dB}$.

In Figure 4, we observe that for $\gamma = 3.8\,\text{dB}$ the outage probability is less than 0.002 within a distance of 2 Km. The increase in the outage probability due to 4 dB of interference temperature is less than 1%, which indicates that the impact on the system performance is completely negligible.
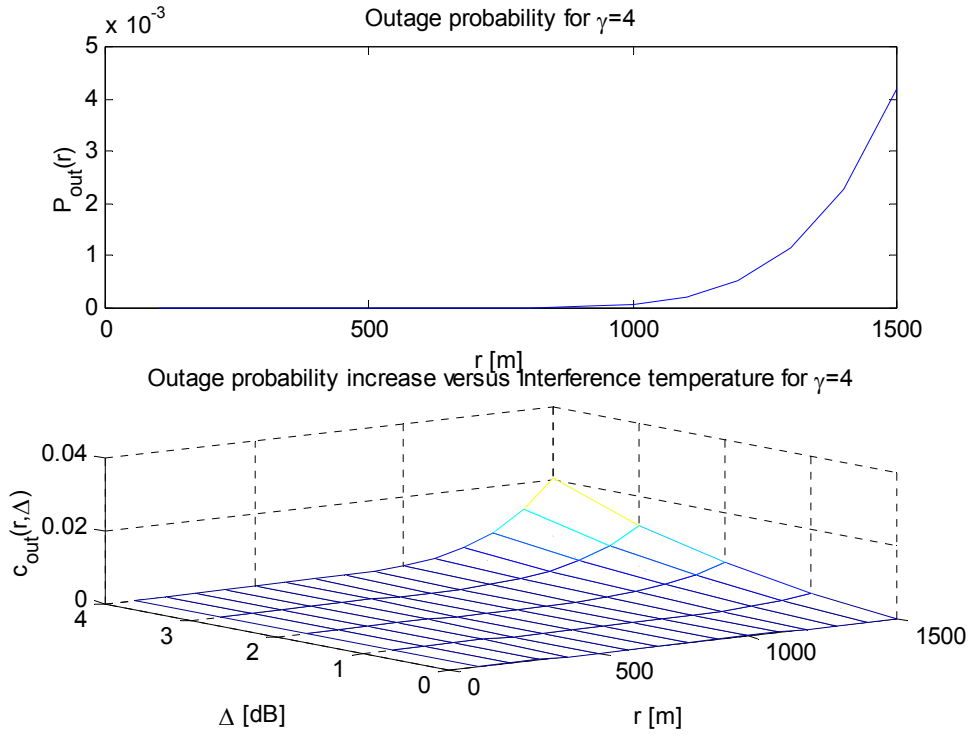
Figure 5 Outage vs. interference temperature for $\gamma = 4 \, \text{dB}$.

In Figure 5, we observe that for $\gamma = 4 \, \text{dB}$ the outage probability is less than

0.002 within a distance of 1.25 Km. The increase in the outage probability due to 4 dB of

interference temperature is less than 1%, which indicates that the impact on the system

performance is completely negligible.

QUALCOMM should clearly state the sizes of its cell coverage areas for urban,

suburban, rural, indoor, etc, along with the outage probabilities as accurately as possible

in light of the details for CDMA technologies. Our analysis reveals only upper bounds of

system outage probabilities for any mobile technology in order to illustrate the

fundamental mistake in QUALCOMM analysis. It is clear that any detailed analysis of the

particular wireless access system would imply much less impact on the system than our

very conservative and overestimated performance losses due to interference

temperature requirement.. Therefore, there is no need to increase the number of the cell sites due to the interference temperature. Also, the mobile users can still operate at the same transmit power parameters without perceiving any significant decrease in terms of quality of service rather than 0.2% increase in outage probability. We note that there will not be any shortage for the battery life.

5. CDMA System Capacity Versus Interference Temperature

In this section, we evaluate the impact of the temperature interference on the system capacity. It is important to note that for the case of the wireless cellular systems, the capacity evaluation should be based on the expression of the CDMA multi-cell capacity[14][15] instead on the formula for Shannon capacity limit.

However, in case of the single cell wireless system, it is well known that the capacity obtained using CDMA technology is usually lower than the capacity obtained using either FDMA or TDMA[16]. For single cell CDMA capacity, all users in the cell should be power controlled to have the same power as received at the base station. Power control is critical to the performance of CDMA systems. Otherwise close users would have a built-in advantage. Therefore, it does not make sense to show the calculations for the impact of the interference temperature on the Shannon capacity considering the bandwidth of 30MHz.

It is also important to make a point here clear that the CDMA technology is mainly designated for wireless cellular systems such that the capacity performance should be evaluated within a multi-cell scenario, where the soft handoff gain and power

---

[14] A. M. Viterbi and A. J. Viterbi, "Erlang Capacity of a Power Controlled CDMA System," IEEE JSAC, vol. 11, No. 6, Aug. 1993.

[15] K. S. Gilhousen, et. al. "On the Capacity of a Cellular CDMA System," IEEE Trans. On Vehicular Technology, Vol. 40, No.2, May 1991.

[16] John Proakis "Digital Communications," McGraw-Hill, Third Edition, 1995.

control contributes to obtaining four to twenty times more capacity than in the case of using FDMA/TDMA technologies. CDMA allows soft handoff such that a mobile may be in communication with two or more base stations. It will then be assigned the one to which the propagation loss is the least. This turns out to reduce the total interference power and increase the system capacity, the number of users allowed per cell.

The cell capacity of a DS-CDMA system is a function of many system-related factors, as follows[17]:

E_b: = energy of transmitted signal per information bit
I_0: = one-sided interference-plus-noise power spectral density
P_n: = background noise power
S: = signal power received at the cell-site receiver
G_p: = signal processing gain
η_f: = frequency reuse efficiency
c_d: = capacity degradation factor due to imperfect power control
Q: = number of sectors
S_f: = source activity factor

As a function of the preceding parameters, the number of the mobile stations, N_{MS}, that can be supported by a DC-CDMA system can be expressed as:

$$N_{MS} = 1 + \frac{c_d \eta_f}{s_f}\left[\frac{QG_p}{E_b/I_0} - \frac{P_n}{S}\right]$$

Now, introducing the interference temperature the CDMA system capacity is slightly changed as below:

$$N_{MS}(\Delta) = 1 + \frac{c_d \eta_f}{s_f}\left[\frac{QG_p}{E_b/I_0} - \frac{P_n(1+\Delta)}{S}\right]$$

The following graphs show the relationships between interference temperature and CDMA system capacity.

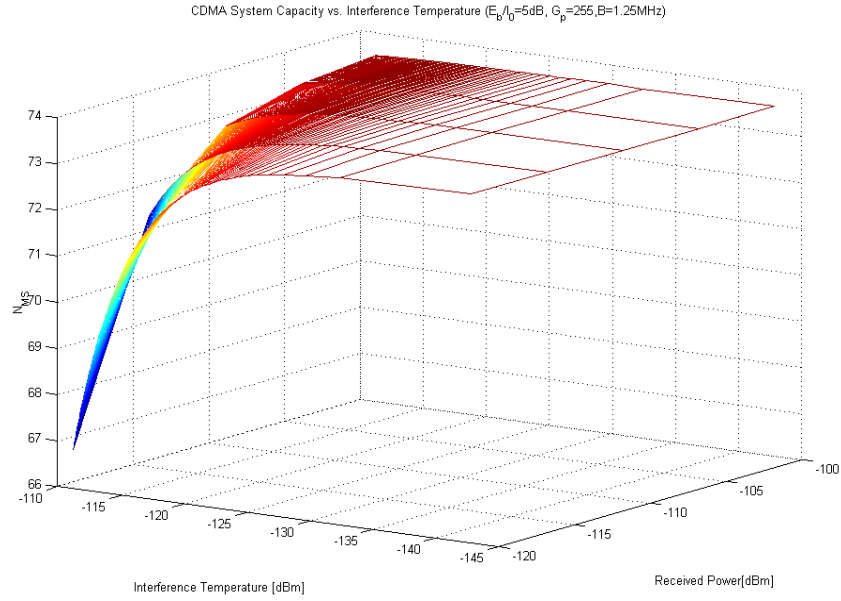[17]J.W. Mark and Weihua Zhuang "Wireless Communications and Networking," Prentice Hall,2003.

Figure 6. CDMA System Capacity vs. Interference Temperature (E_b/N_0=5dB)

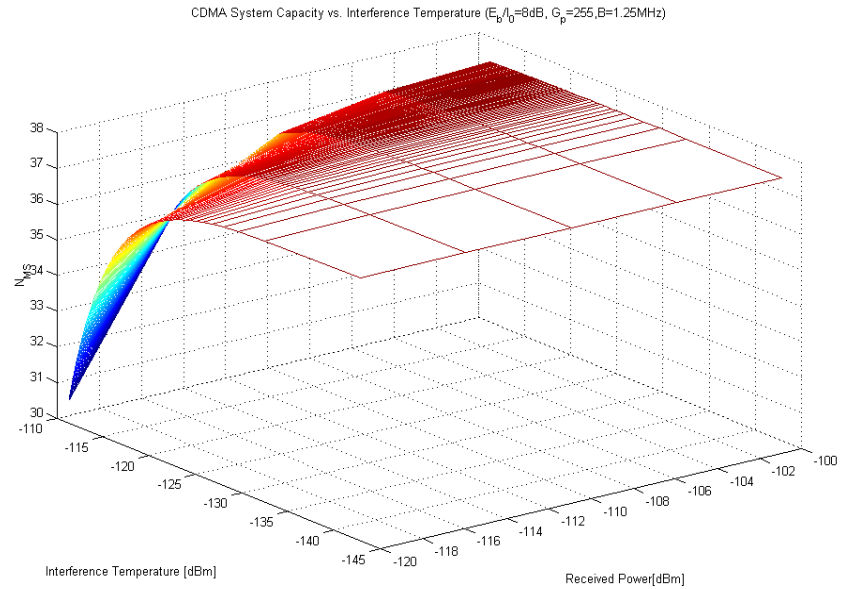**Figure 7 CDMA System Capacity vs. Interference Temperature (E_b/N_0=8dB)**

In the above example of CDMA capacity evaluation versus Interference Temperature there have been considered the bandwidth $B = 1.25\,\mathrm{MHz}$ and the processing gain $G_p = 255$. The two graphs in Figures 4, and 5 were drawn for E_b/N_0 values of 5 dB and 8 dB, respectively. In Figure 6, the system capacity remains 73 while the

Interference Temperature is increased from –135 dBm to –120 dBm. Similarly in Figure 7, we have noticed that the CDMA system capacity is unchanged while the Interference Temperature ranges between –135 dBm and –115 dBm. Thus, system capacity is not affected adding an Interference Temperature of 3 dB above the noise. Other calculations of the CDMA capacity for values of parameters such as the propagation constant γ and the shadow fading standard deviation, as well as soft handoff effects, other than those chosen here, can be also included[18].

Below we show that the particular value $E_b/N_0 = 5dB$, as our first numerical example above is realistic. The probability of bit error P_e for PSK in the presence of additive white Gaussian noise is readily found to be given, in terms of complementary error function, as following[8]:

$$P_e = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \cong \frac{1}{2} \frac{e^{-E_b/N_0}}{\sqrt{\pi E_b/N_0}}$$

The probability of error thus varies inversely as the exponential of E_b/N_0. For example for $P_e = 10^{-5}$ using FSK modulation, $E_b/N_0 = 12.6dB$; for $P_e = 10^{-3}$, $E_b/N_0 = 9.6dB$. These numbers for PSK and FSK require accurate phase synchronization between transmitter and receiver. The price paid is a loss of about 0.7 dB., i.e., non-coherent FSK requires an increased signal energy or power of 0.7 dB., the required E_b/N_0 increases to 13.3 dB, for example, if $P_e = 10^{-5}$ is desired. It may also be shown that Differential PSK and FSK requires almost a dB more of signal power than does PSK: $E_b/N_0 = 10.5dB$ for $P_e = 10^{-5}$. These numbers can be improved considerably by coding the binary signals prior to carrying out the carrier modulation. As an example, if rate -1/2 convolutional coding is used, with PSK as the modulation scheme, the required energy

---

[18] A.J. Viterbi, "CDMA, Principles of Spread Spectrum Communication," Addison-Wesley, Reading, MA 1995.

to noise spectral density E_b/N_0 ranges from 4 to 6 dB at $P_e = 10^{-5}$, depending on the type of coder used, a considerable reduction from the 9.6 dB figure[8].

In Shared Spectrum's original comments in this proceeding, we proposed an Interference Temperature level that is 3 dB <u>below</u> the pre-amplifier thermal noise level. We have shown above that increasing the noise by 15 dB <u>above</u> the noise level, the CDMA capacity is unchanged. The unmistakable conclusion is that a small increase in Interference Temperature does not significantly affect the CDMA system capacity.

April 5, 2004